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(54) METHOD OF AND DEVICE FOR DETECTING A FLUID-LIQUID INTERFACE IN A CONTAINER

(71) We, VSESOJUZNY NAUCHNO-ISSLEDOVATELSKY I KONSTRUKTORSKY INSTITUT "TSVETMETAVTOMATIKA" a body corporate of the Union of Soviet Socialist Republics, of Dmitrovskoe shosse, 129 Moscow, Union of Soviet Socialist Republics, do hereby declare the invention for which we pray that a patent may be granted to us, the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to automatic control of technological parameters in various production processes in various industries by means of acoustic vibrations and more particularly to a method of and a device for detecting a fluid-liquid interface in a container. The invention can be used in automatic systems of controlling hydrometallurgical and ore-dressing processes in ferrous and non-ferrous metallurgy, in chemical, petro-chemical, food stuffs and other industries for automatic non-contract control of interfaces of various media.

Detection of interfaces is based on differences in properties of such media. Production processes being controlled may be characterized by various factors of destabilization of the medium properties, which hinder the detection of fluid-liquid interfaces. Among these factors are varying or lowered density of liquids, elevated pressures and viscosity, permittivity variations, stirring of the liquid by gas bubbles, a foam layer of variable consistency on the liquid surface and diverse suspensions inside the liquid.

The main requirement imposed upon methods and devices for detecting fluid-liquid interfaces is minimizing the effect of said destabilizing factors on the reliability and accuracy of detection. It is also required that the method of detection be sensitive, safe for the device personnel, that the device be simple in construction, and its market price should be low.

For detecting interfaces use can be made of methods and devices which, according to their technological features, can be classified into two groups; probe and non-contact. In the methods and devices belonging to the first group sensitive elements, which provide information on the interface being detected, are introduced into a reservoir containing said media and contact these media. As far as the second group is concerned, sensitive elements are placed outside the reservoir being controlled and are not in contact with the media, whose interface is to be detected.

It is an object of the present invention to provide a method of detecting a fluid-liquid interface in a container and a device for performing such method, which will ensure detection within a wide range of physicochemical composition, state, and properties of the media.

Another object of the invention is to increase the accuracy of the detection of interfaces.

A further object of the invention is to simplify the design of the device and cut down its operation costs and market price.

According to one aspect of the present invention there is provided a method of detecting a fluid-liquid interface in a container having a wall homogeneous across its thickness comprising the steps of; producing acoustic vibrations, introducing the acoustic vibrations into a sound conducting medium which contacts a wall of the container in such a fashion that mechanical vibrations are excited within the wall, the mechanical vibrations propagating in a direction transverse to the thickness of

the wall sensing the mechanical vibrations by positioning a second sound conducting medium on the wall of the container in the path of the mechanical vibrations such that acoustic vibrations are excited within the second sound conductor, detecting the relative position of the interface by analyzing the amplitude attenuation due to energy dissipation by the mechanical vibrations while propagating within the wall of the container.

According to another aspect of the invention there is provided a device for detecting a fluid-liquid interface in a container having a wall homogeneous across its thickness comprising an emitter and a receiver of acoustic vibrations each mounted in contact with a respective sound conducting medium, one sound conducting medium contacting a section of the wall of the container in such a fashion that mechanical vibrations are excited within the section of the wall by acoustic vibrations emitted by the emitter to propagate in a direction transverse to the thickness of the wall, the other sound conducting medium contacting the section of the wall in the path of the mechanical vibrations and in such a fashion that acoustic vibrations are excited within the sound conducting medium and impinge upon the receiver means being provided for determining the relative position of the interface by an analysis of the amplitude attenuation due to energy dissipation by the mechanical vibrations while propagating within the wall of the container.

The above-described method of detecting a fluid liquid interface in a container having the required homogeneity hereinafter called a monolayer reservoir, and the device for performing said method have a number of advantages over the known methods and devices.

The above-described method and device allow a considerable decrease in the errors when detecting interfaces in monolayer reservoirs, and hence, an increase in the accuracy and reliability of detection.

First, the herein-proposed method may exclude errors caused by the propagation of the acoustic wave in the media whose interface is being detected in the reservoir since the wave propagating in said media need not be recorded.

Since in the present method the parameter employed for detecting the interface, the amplitude of the acoustic wave which is transformed from mechanical vibrations propagating along the reservoir wall, is independent of the acoustic wave propagating in the liquid media in the reservoir the effect of waves propagating in the liquid media may be ignored.

Furthermore, the design of the device for realizing the herein-proposed method is essentially simplified owing to the possibility of using an emitter of reduced size and an essentially less powerful generator of electric oscillations than are used in conventional systems. This becomes possible because in the herein-proposed device there is no need to drastically increase the power of the acoustic wave, whereas in the prior-art devices this is mandatory for ensuring the passage of the acoustic wave through large industrial reservoirs. In the herein-proposed device such drastic increase in the power of the acoustic wave is obviated due to the fact that the informative acoustic wave is received by the receiver within a section remote from the section within which the acoustic wave is transmitted by practically one order of magnitude.

The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 is a general view of a monolayer reservoir with an emitter and a receiver of an acoustic wave mounted on a side surface of the reservoir;

Figure 2 is a top view of the same arrangement as in Figure 1 (with the reservoir shown in cross-section);

Figure 3 shows the device of a first embodiment of the present invention for detecting a fluid-liquid interface in monolayer reservoirs, provided with sound conductors (the reservoir being shown in partial longitudinal section);

Figure 4 shows a section of a reservoir wall with an emitter of a wave of acoustic vibrations mounted thereon with the aid of a second embodiment of a sound conductor (shown in partial longitudinal section);

Figure 5 is a side view of the same arrangement as shown in Figure 4;

Figure 6 shows a section of a reservoir wall with an emitter of a wave of acoustic vibrations mounted on said section with the aid of a sound conductor made in accordance with a third embodiment thereof (shown in partial longitudinal section);

Figure 7 is a side view of the same section as shown in Figure 6;

Figure 8 shows a section of a reservoir wall with an emitter of a wave of

acoustic vibrations mounted on said section with the aid of a sound conductor made in accordance with a fourth embodiment thereof (shown in partial longitudinal section);

Figure 9 is a side view of the same section as shown in Figure 8;

Figure 10 shows the same device as shown in Figure 3 with an electronic channel for the passage of a reference signal in the electric circuit of the proposed device;

Figure 11 shows same as device as shown in Figure 3, with sound conductors made in accordance with a fifth embodiment thereof and with an electronic/acoustic circuit for the passage of a reference signal in the electric circuit of the proposed device;

Figure 12 shows same device as shown in Figure 3, with sound conductors made in accordance with a sixth embodiment thereof and with an electronic/acoustic circuit for the passage of a reference signal in the electric circuit of the proposed device;

Figure 13 shows the same device as shown in Figure 3 with additional components so as to provide an electric circuit providing pulse-excitation of a wave of acoustic vibrations and frequency monitoring of a received wave;

Figure 14 shows a section of a reservoir wall with an emitter of a wave of acoustic vibrations mounted on said section with the aid of a sound conductor made in accordance with a seventh embodiment thereof (shown in partial longitudinal section);

Figure 15 shows a section of a reservoir wall with an emitter of a wave of acoustic vibrations mounted on said section with the aid of sound conductor made in accordance with an eight embodiment thereof (shown in partial longitudinal section);

Figure 16 shows a section of a reservoir wall with an emitter of a wave of acoustic vibrations mounted thereon with the aid of a sound conductor made in accordance with a ninth embodiment thereof (shown in partial longitudinal section);

Figure 17 shows a section of a reservoir wall with an emitter of a wave of acoustic vibrations mounted on said section with the aid of a sound conductor made in accordance with a tenth embodiment thereof (shown in partial longitudinal section);

Figure 18 shows a section of a reservoir wall with an emitter of a wave of acoustic vibrations mounted on said section with the aid of a sound conductor made in accordance with an eleventh embodiment thereof (shown in partial longitudinal section);

Figure 19 shows a section of a reservoir wall with an emitter of a wave of acoustic vibrations mounted on said section with the aid of a sound conductor made in accordance with a twelfth embodiment thereof (shown in partial longitudinal section);

Figure 20 shows a section of a reservoir wall with an emitter of a wave of acoustic vibrations mounted on said section with the aid of a sound conductor made in accordance with a thirteenth embodiment thereof (shown in partial longitudinal section).

A proposed device for detecting fluid-liquid, being gas-liquid or fluid-liquid, interfaces in monolayer (as hereinbefore defined) reservoirs comprising an emitter 1 (Figure 1) of a wave 2 (Figure 2) of acoustic vibrations, said emitter being mounted with the aid of a sound conductor 3 on a wall 4 of a monolayer reservoir 5 containing gas and liquid media 6 (Figure 1) and 7 with an interface 8. The emitter 1 is mounted on a section 9 in such a way that mechanical vibrations 10 are excited by the transmitted wave 2 of acoustic vibrations within the section 9 of the wall 4 (Figure 2), said mechanical vibrations propagating in a prescribed direction.

The wave 2 of acoustic vibrations excites the known forms of mechanical vibrations within the wall, these vibrations include different modes of Lamb waves.

The device also comprises a receiver 12 of an acoustic wave 13 transformed from the mechanical vibrations 10, said receiver 12 being mounted on the section 9 with the help of a sound conductor 11 in the path of propagation of the mechanical vibrations 10. A generator 14 (Figure 3) of electric oscillations is coupled to the emitter 1 and a circuit constituted by a series-connected amplifier 15 of electric signals and a recorder 17 (Figure 3) of the amplitude of these signals is coupled to the receiver 12, the amplitude of said electric signals being dependent on the type of medium 16 contacting the section 9 of the wall 4, said medium being above or below the interface 8 (Figure 1).

For the wave of acoustic vibrations transmitted into the reservoir 5 to travel in a direction transverse to the thickness of the wall 4, the effective area 18 of the sound conductors 3, 11, on which the emitter 1 and the receiver 12 are mounted, respectively, and the contact area 19 of these sound conductors 3, 11 lie at angles θ with respect to each other, said angles being determined from the relationship

$$\theta = \text{arc Sin} \frac{C_3}{C},$$

where C_3 is the velocity of propagation of the acoustic waves 2, 13 in the sound conductors 3, 11;

C is the velocity of propagation of the mechanical vibrations 10, excited by the wave 2 of acoustic vibrations, along the wall 4 of the reservoir 5.

The sound conductors 3, 11 are made of a material in which the velocity of propagation of the acoustic waves 2, 13 is less than the velocity of propagation of the mechanical vibrations 10 in the wall 4 of the reservoir 5.

The sound conductors 3, 11 can be made either from the same material as each other or from different materials. In the latter, case, as follows from relationship (1), the angles θ in the sound conductors 3, 11 will also be different. In all the embodiments described below the sound conductors 3, 11 are assumed to be made from the same material. In the embodiment being described the sound conductors 3, 11 are made of polymethylmethacrylate but they can alternatively be made of a suitable solution of ethyl alcohol.

The sound conductors 3, 11 are mounted with their contact surfaces 19 on the wall 4 of the reservoir 5 within the section 9 being excited with the help of a flange 20, said flange being fixed by studs (not shown in the drawing) preliminarily welded to the reservoir 5 and passing through appropriate holes in the flange 20. Another version is also possible when the flange 20 is cemented to the wall 4 of the reservoir 5.

Part of the surface of the sound conductors 3, 11 in the embodiment described is coated with a layer 21 of a material absorbing acoustic waves, the material being a mixture of an epoxy resin and a polymerizing agent, with a tungsten powder as a filler.

As the emitter 1 of a wave of acoustic vibrations, use is made of an emitter of piezoelectric type (see, for instance U.S. Patent No. 2,931,223). The receiver 12 is of similar design as the emitter 1. A generator 14 employs a well-known continuous crystal-stabilized oscillator circuit. A recorder 17 of the amplitude of the electric signals is made according to the known scheme (see, for example, U.S. Patent No. 3,345,861) of an analogue recorder. The recorder 17 can be made as a relay block when a relay-contact signalization as to the presence of the interface being detected at a prescribed level is required.

The above-described embodiment is used in the simplest case, that is when the cross-section of the wall 4 of the reservoir 5 is constant.

The effect of variation in the thickness of the wall 4 of the reservoir 5 on the detection of the interface 8 (Figure 1) between the media 6 and 7 can be diminished by exciting the section 9 of the wall 4 by a divergent or convergent wave of acoustic vibrations, with the angle of entry selected from the relationship:

$$\frac{\text{Sin}\ \theta_1}{\text{Sin}\ \theta_2} \geqslant \frac{C_1}{C_2}, \qquad (2)$$

where θ_1 and θ_2 are the angles of entry of the wave 2 (Figure 4) of acoustic vibrations determined by the direction of propagation of said wave 2 and by the normal to the wall 4 of the reservoir 5 in the zone of entry.

C_1 and C_2 are respective maximum and minimum velocities of propagation of the mechanical vibrations 10 within the section 9 of the wall 4, said vibrations being excited by the wave 2 of acoustic vibrations.

For each value of the variable thickness of the wall 4 in the range from d_1 to d_2 there exists an angle of entry, satisfying the conditions of equality of the velocity of the trace of the introduced wave 2 to that of propagation of the mechanical vibrations 10 within said thickness range of the wall 4, for excitation of the mechanical vibrations 10 being thus maintained.

To introduce a convergent or divergent wave within the range of angles θ_1 to

θ_2, each of the sound conductors 3, 11 in a first embodiment, is made of two parts 22 (Figure 4) and 23, the material of said parts being different as to the velocity with which the waves 2, 13 (Figure 3) of acoustic vibrations propagate therein. The parts 22 (Figure 4) and 23 have a cylindrical contact area 24 with the axis of symmetry of the cylinder lying in the same plane as the axis of the emitter 1 or of the receiver 12 (Figure 3) with said axis of symmetry being perpendicular to the axis of the emitter or receiver. The radius of the contact areas 24 (Figure 4) is determined from the relationship

$$R \leq \frac{C_1 + C_2}{C_4 + C_5} \left| \frac{C_4 - C_5}{C_1 - C_2} \right| A\, Ctg\, \theta\ ; \qquad (3)$$

where C_4 and C_5 are the velocities of propagation of the wave 2, 13 of acoustic vibrations in the separate parts 22 (Figure 5) and 23 respectively of the sound conductors 3, 11 (Figure 3);

A is the length of the effective area 18 of the sound conductors 3, 11 in the plane containing the direction of propagation of the mechanical vibrations 10 in the wall 4 and the normal to this area 18. The central ray 25 (Figure 4) of the wave 2 of acoustic vibrations passes through the contact area 24 without refraction and enters the wall 4 at an angle to the normal equal to the angle θ of inclination of the effective area 18 of the part 22 of the sound conductor 3. Side rays 26 and 27 are refracted on said area 24 and enter the wall 4 at angles θ_1 and θ_2, said angles being, respectively, greater and smaller than the angle θ of entry of the central ray 25.

To eliminate volume reverberation of the sound conductors 3, 11 (Figure 3) caused by multiple reflections of the wave 2, 13 of acoustic vibrations, said sound conductors 3, 11 are partly covered with a layer 21 (as in the embodiment shown in Figure 3) of a material which absorbs acoustic waves.

Diminution of the adverse effect caused by variations in thickness of the wall 4 of the reservoir 5 is also attained if the effective area 18, of the sound conductor 3 (Figure 6) of the emitter 1 and of the sound conductor 11 (Figure 3) of the receiver 12, is made cylindrical with a radius of curvature R (Figure 6). The ratio between said radius R and the length A of the area 18, in the plane containing the normal to said area 18 and the direction of propagation of the mechanical vibrations 10 excited in the wall 4, being determined from the expression:

$$\frac{A}{R} \geq 2 \frac{C_1 - C_2}{C_1 + C_2} \tan \theta \qquad (4)$$

The emitter 1 and the receiver 12 (Figure 3) are made in the form of a part of a hollow cylinder with an inner radius of curvature equal to the radius R (Figure 6) of the effective area 18 (Figure 7) of the sound conductors 3, 11 (Figure 3). A convergent ray bundle is thus introduced into the wall 4 within the range of angles from θ_1 (Figure 6) to θ_2, ensuring optimum excitation of the mechanical vibrations 10 of the section of the wall 4 which has a thickness varying from d_1 to d_2. The effect of variations in thickness of the wall 4 of the reservior 5 may also be diminished if the length A of the effective area 18 (Figure 8) of the sound conductors 3, 11 (Figure 3) in the plane containing the normal to the area 18 and the direction of propagation of the mechanical vibrations 10 in the wall 4 is determined from the relationhip:

$$A \leq K \left| \frac{C_1 + C_2}{C_1 - C_2} \right| \lambda \cdot Ctg\, \theta\ ; \qquad (5)$$

where k is a coefficient determined by the shape of the effective area 18 of the sound conductors 3, 11, said coefficient being equal to 0.86 for a round effective area and to 0.7 for a rectangular one.

(the numeric values are obtained from analytical expressions for directivity patterns of emitters having the emitting surfaces of the above-stated shapes);

λ is the wave length of the wave 2, 13 of acoustic vibrations in the sound conductors 3, 11;

θ is the angle of inclination of the effective area 18 of the sound conductors 3, 11.

The minimum distance H_{min} (Figure 9) between the effective area 18 and the

contact area 19 of the sound conductors 3, 11 (Figure 3) is determined from the relationship:

$$H_{min} > \frac{A^2}{4\lambda} \cos\theta \qquad (6)$$

As a result, plane front 28 (Figure 8) of the wave 2 of acoustic vibrations, preserved over a distance B, is transformed, when approaching the contact area 19, into a partially spherical front with divergent rays, the angle of entry of said rays, into the wall 4 lying within the range from the maximum angle θ_1 to the minimum angle θ_2. Said angles ensure excitation of the mechanical vibrations 10 within the prescribed thickness range from d_1 to d_2 of the wall 4 of the reservoir 5.

Instability of excitation of the wave 2 of acoustic vibrations in the sound conductor 3, used for exciting mechanical vibrations 10 within a prescribed section of the wall 4 of the reservoir 5, is eliminated by incorporating into the electric circuit of the proposed device an additional circuit (Figure 10) constituted by; a series connected shaper 29 adapted to shape a reference electric signal from electric oscillations of the generator 14, the input of said shaper being coupled to the output of the generator, a block 30 for comparing a data or informative electric signal with a reference signal, and a shaper 31 adapted to shape a data or informative electric signal from electric signals of the amplifier 15, the input of the shaper 31 being coupled to the output of the amplifier. The output of the comparison block 30 is coupled to the recorder 17 which is fed with a signal which, depending on the object of the detection exercise, is proportional either to the difference or to the ratio between the informative and the reference electric signals.

When the device incorporates the additional circuitry consisting of the blocks 29, 30 and 31 in Figure 10, the effect of variation of the amplitude of the electric oscillations of the generator 14 on the accuracy of detection of the gas-liquid or fluid-liquid interface 8 between the media 6 and 7 (Figure 1) in the monolayer reservoir 5 is eliminated owing to the fact that the variation effects the amplitudes of the reference and of the informative electric signals equally.

The conditions of introducing the wave 2 (Figure 10) of acoustic vibrations through the contact area 19 into the wall 4 may change during the device operation, this will cause changes in the amplitude of the mechanical vibrations 10 within the excited section 9 of the wall 4 and, consequently will cause errors in detecting the interface 8 (Figure 1).

To eliminate these errors, additional mechanical vibrations are produced within the section 9 of the wall 4 by additional acoustic vibrations, the attenuation of the latter mechanical vibrations being different from the attenuation of the mechanical vibrations excited by the first, or primary, wave. The additional mechanical vibrations include the known forms of vibration, including Lamb waves. The interface 8 is determined from the ratio between the amplitudes of the mechanical vibrations excited by the primary and by the additional, or secondary waves.

To effect the secondary excitation of mechanical vibrations in the wall 4 of the reservoir 5 by a wave of acoustic vibrations, two embodiments of the device are proposed shown in Figures 11 and 12 respectively.

In the first of these embodiments, the device comprises the above-cited emitter 1 (Figure 11) of the wave 2 of acoustic vibrations, the emitter being coupled to the generator 14 of electric oscillations and mounted on the sound conductor 3, and the receiver 12 of the acoustic wave 13. The receiver is coupled to the amplifier 15 and mounted on the sound conductor 11. The electric circuit of the presently-described embodiment of the device comprises also the recorder 17, the shaper 29 of the reference electric signal, the block 30 for comparing the informative electric signal with the reference one, and the shaper 31 of the informative electric signal.

The sound conductors 3 and 11 in the above described embodiment of the device have an additional effective area 32 making the angle γ with the contact area 19, said angle being selected by the relationship:

$$\gamma = \arc \sin \frac{C_3}{C_6}, \qquad (7)$$

where C_6 is the velocity of propagation of the secondary mechanical vibrations excited within the section 9 of the wall 4 of the reservoir 5.

The device also has an additional emitter 33 of a wave 34 of acoustic vibrations and an additional receiver 35 of an acoustic wave 36, the emitter and receiver being mounted on the additional effective areas 32 of the corresponding sound conductors 3 and 11. The additional emitter 33 is coupled together with the main emitter 1 to the generator 14 of electric oscillations. The electric circuit of the device also includes an additional amplifier 37 of electric signals, said amplifier being coupled to the additional receiver 35 of the acoustic wave 36, said wave 36 being transformed from mechanical vibrations 38 excited in the wall 4 by the wave 34, the attenuation of the mechanical vibrations 38 is different from the attenuation of the primary excited mechanical vibrations 10. The output of the amplifier 37 is coupled to the input of the shape 29 which is adapted to shape the reference electric signal, the output of the shaper being coupled to one input of the block 30 for comparing the informative electric signal with the reference signal. Another input of the comparison block 30 is coupled to the output of the shaper 31 adapted to shape the informative electric signal, the input of the shaper being coupled to the output of the amplifier 15. The output of the comparison block 30 is coupled to the recorder 17.

In the above described embodiment of the device it is expedient to select the distance E between the projections of the centres of the main and additional effective areas 18 and 32, respectively, on the contact area 19 from the relationship:

$$E=H_1 \tan \theta - H_2 \tan \gamma \qquad (8)$$

where H_1 and H_2 are the heights of the centres of the main and additional effective areas 18 and 32, respectively, above the contact area 19 of the sound conductors 3 and 11.

The provision of an additional acoustic circuit (the emitter 33 of the wave 34 of acoustic vibrations—mechanical vibrations 38 in the wall 4—the receiver 35 of the wave 36) and of the additional electric circuit (the amplifier 37—the shaper 29) make it possible to increase considerably the control accuracy in the event of instabilities when introducing the wave 2 of acoustic vibrations into the wall 4 through the contact area 19 of the sound conductor 3 and during the reception of the wave 13 in the sound conductor 11 through its contact area 19.

In the embodiment of the device illustrated in Figure 12 the sound conductors 3 and 11 have a reflector area 39 for aiding the production and receipt of the secondary excitation of the section 9 of the wall 4, the reflector area making an angle β with the effective area 18, the angle β being determined from the relationship:

$$\beta = \frac{\pi}{2} - \left(\theta - \arcsin \frac{C_3}{C_6}\right) ; \qquad (9)$$

The secondary excitation of mechanical vibrations (38) in the wall 4 propagating therewith with the velocity C_6 is effected with the aid of the wave 34 of acoustic vibrations, the wave 34 being transformed from wave 40 of the emitter 1 after the wave 40 has been reflected from the reflector area 39. The additional wave 36 transformed from the secondary excited mechanical vibrations (38), after reflection from the reflector area 39 in the sound conductor 11 and transformation into acoustic wave 41, is received by the receiver 12 which also receives the main acoustic wave 13. The electric circuit of the presently described embodiment of the device comprises a circuit constituted by a series-connected first selection or timing block 42 (the input of this block being coupled to the output of the amplifier 15), the shaper 31, and the comparator block 30. The circuit also includes the reference signal shaper 29, the output of this shaper being coupled to the input of the comparator block 30, second selection block 43, the input of this block being coupled to the output of the amplifier 15 whilst the output of the block is coupled to the input of the shaper 29. The electric circuit incorporates a selecting pulse shaper 44 outputs of this shaper being coupled to controlled inputs of the selection blocks 42 and 43.

The generator 14 in the presently described embodiment, generates pulse-amplitude modulated oscillations, (having a duration τ in each modulation period). The input of the selecting pulse shaper 44 is coupled to the output of the generator. The selection blocks 42 and 43 are made according to the well-known circuit of an amplifier with a controlled additional input for the selecting pulse, the control is time-coincident with the reception of the selected signal coming from the amplifier 15. The selecting pulse shaper 44 is made in accordance with the circuit of a gate

pulse generator (see, for example, the book by I. N. Yermolov "Methods of Ultrasonic Flaw Detection", in Russian, Moscow, MGI publishers, 1966, pp. 118—119).

In the detection of an interface 8 (Figure 1) between media which differ considerably in their physical properties, the frequency of the mechanical vibrations within the excited section 9 of the wall 4 depends on the location of the interface. The conditions of excitation of the mechanical vibrations 10 by the wave 2 of acoustic vibrations are changed; the amplitude of these mechanical vibrations and that of the electric oscillations at the output of the receiver 12 changes correspondingly. This may cause considerable errors in detecting the interface 8 (Figure 1).

To eliminate these adverse effects, the section 9 of the wall 4 (Figure 2) is periodically excited by a pulse wave 2 of acoustic vibrations, the spectrum of the pulse being selected from a range including but exceeding that of the frequency of the mechanical vibrations dictated by the wall 4 at different locations of the interface 8 (Figure 1).

The vibration of the reservoir wall is dependent upon the loading of the wall, that is, it is dependent upon the location of the interface and upon the type of medium contacting the wall. By using a pulsed wave to excite mechanical vibrations within the wall, the range of frequencies associated with the pulse including but exceeding the range of frequencies dictated by the wall, the preferred frequency will always be excited. The carrier frequency of the pulsed acoustic wave 13 is also measured, and this frequency is used for ascertaining the type of the liquid when the interface 8 (Figure 1) is located above or below the vibrating section 9 of the wall 4 (Figure 2) of the reservoir 5.

To perform periodic excitation of the section 9 of the wall 4 by the pulse wave of acoustic vibrations, the generator 14 (Figure 13) in the electric circuit of this embodiment includes a shaper 45 of wide-spectrum electric pulses and a power amplifier 46 coupled to the shaper, the output of the amplifier 46 being coupled to the emitter 1 of the wave 2 of acoustic vibrations. The electric circuit also comprises the informative signal shaper 31, the input of this shaper being coupled to the amplifier 15, the comparator block 30, the input of block 30 being coupled to the output of the shaper 31 and the output of the shaper 29 of the reference electric signal, the input of the shaper 29 being coupled to the power amplifier 46. The electric circuit also incorporates a block 47 adapted to measure the frequency of the electric signal, the input of said block 47 being coupled to the output of the amplifier 15. The output of the comparison block 30 is coupled to the recorder 17.

The shaper 45 of the wide-spectrum electric pulses in this embodiment of the device is made as a shaper of electric video pulses employing a well-known circuit of a blocking oscillator. The duration τ_0 of these video pulses is selected in accordance with the relationship:

$$\tau_0 \cong 0.5\ f_0^{-1} \qquad (10)$$

where f_0 is the mean pass band frequency of the emitter 1 and, consequently, of the receiver 12.

If a piezoelectric plate is used as an active element in the emitter and in the receiver, the value f_0 is the frequency of resonance vibrations of this plate.

In this embodiment of the device the power amplifier 46 is made in accordance with the well-known circuit of an emitter follower.

The frequencies which may be excited by the primary excited mechanical vibrations 10 and by the secondary excited mechanical vibrations 38 (Figures 11, 12) change with variations in the thickness of the wall 4 of the excited section 9 of the reservoir 5. These change the conditions of excitation of mechanical vibrations 10, 38, their subsequent transformation into acoustic waves, the amplitude of said mechanical vibrations and the magnitude of the electric signals at the outputs of the receivers 12, 35. As a result, considerable errors in detecting the interface 8 (Figure 1) arise.

To diminish these errors, the section 9 of the wall 4 (Figure 2) is periodically excited by a pulse wave of acoustic vibrations, the relative spectrum width of said wave being selected equal to or exceeding the effect of the relative changes in the thickness of the vibrating section 9 of the wall 4 of the reservoir 5:

$$\frac{\Delta f}{f_3} = \frac{2(f_2 - f_1)}{f_1 + f_2} \geqslant \frac{2(d_1 - d_2)}{d_1 + d_2} \quad ; \qquad (11)$$

where $f=f_2-f_1$ is the absolute spectrum width of the pulse wave of acoustic vibrations;

f_2 and f_1 are the respective upper and lower boundaries of the spectrum of the pulse wave of acoustic vibrations;

$f_3=0.5\ (f_1+f_2)$ is the mean frequency of said spectrum;

d_1 and d_2 are the respective maximum and minimum thickness of the wall 4 of the reservoir 5.

To accomplish the present engineering solution, the sound conductors 3, 11 in the device shown in Figure 13 are made of fused quartz, porcelain, silica glass, tin, lead, or tin-lead alloys having an acoustic impedance Z in the range from 0.3 to 1.7 of the acoustic impedance Z_0 of the emitter 1 and of the receiver 12 of the acoustic wave.

Averaged values of the acoustic impedance Z_0 (in units of 10^6 kg/m²s) of piezoelectric emitters and receivers; X-shaped quartz crystals. Lead meta-niobate, barium titanate, and lead zirconate-titanate are given in Table 1.

TABLE 1

X-shaped quarts crystal	Lead meta-niobate	Barium titanate	Lead zirconate titanate
15.2	16	30.2	36.5

Average values of the acoustic impedance Z (in units of 10^6 kg/m²s) and of the velocity C_3 (m/s) of the sound conductors 3, 11 made of said materials are given in Table 2.

TABLE 2

Material	Fused quartz	Porcelain	Silica glass	Tin	Lead	Lead-tin-alloy, % Pb Sn	Pb Sn	Pb Sn
						25-75	50+50	75+25
Z	13	13.5	15	24.2	24.6	24.3	24.5	24.5
C_3	5,570	5,600	5,550	3,320	2,160	3,030	2,740	2,450

This makes it possible to broaden considerably the spectrum of the wave of acoustic vibrations and, consequently, to decrease the errors caused by the variable thickness of the wall 4 of the reservoir 5.

The temperature of the sound conductors 3, 11 and, consequently, the velocity $\bar{C}_3$ of propagation of the wave 2, 13 of acoustic vibrations change with the temperature of the wall 4 of the reservoir 5. As a result, the conditions (1) and (7) of the primary and secondary excitation of the mechanical vibrations 10, 38 (Figures 11, 12) in the wall 4 of the reservoir 5 are disturbed, and additional temperature errors in detection of the interface 8 (Figure 1) arise.

These errors are diminished by resorting to particular design of the sound conductors 3, 11, said conductors in the subsequent embodiments of the device presented in Figures 14—20 being described with reference to one sound conductor 3 as an example.

The shape of the sound conductors 3 presented in Figures 14—20 is similar to that of the sound conductors presented on Figures 3, 4, 6, 11 and 12.

However, the sound conductor 3 in the embodiments shown in Figures 14—20 is made on the basis of aqueous solutions of alcohols or alkalies, or acids, or salts of inorganic acids having an approximately parabolic temperature dependence of the velocity C_3 of propagation of the wave 2 of acoustic vibrations, the concentrations of the solutions being so selected that the maximum value $C_{3\ max}$ of the velocity of propagation of the wave 2 lies in the range of the mean temperature t_0 of the wall 4 of the reservoir 5.

Given below is Table 3 which presents the values of $C_{3\ max}$ and t_0 for water and for a number of aqueous solutions of various media: sulphuric acid H_2SO_4, nitric acid HNO_3, hydrochloric acid HCl, alkali NaOH, ethyl alcohol C_2H_5OH, zinc sulphate $ZnSO_4$, formamide $HCONH_2$, and acetonitrile CH_3CN with a weight concentration q, which have said parabolic temperature dependence as to the velocity of propagation of the wave 2 of acoustic vibrations therein.

TABLE 3

Medium dissolved in water	H_2O	H_2SO_4		HNO_3		HCl		NaOH
q, %	0	33	20	27	24	30	8	12
t_0, °C	74	30	50	30	50	30	50	30
C_{3max}, m/s	1,555	1,565	1,520	1,525	1,530	1,510	1,760	1,860
Medium dissolved in water	C_2H_5OH		$ZnSO_4$		$HCONH_2$		CH_3CN	
q, %	12.5	16	6.7	12	20	36.5	10	17
t_0, °C	40	20	60	40	50	30	50	30
C_{3max}, m/s	1,580	1,605	1,630	1,665	1,565	1,575	1,550	1,545

The sound conductors 3 shown in Figures 14, 18, 19, and 20 consists of a hollow body 48 filled with an aqueous solution 49 of a compound selected from Table 3, the compound having said parabolic temperature dependence as to the velocity of propagation of the wave 2 of acoustic vibrations. In the sound conductors shown in Figures 14, 16, 17, 18, and 19 the layer 21 made of a material absorbing acoustic waves, is located on the inner surface of the hollow body 48. The emitter 1 of the wave 2 of acoustic vibrations is located in the body 48 at an angle prescribed by equation 1 and appropriately sealed. If an aqueous solution of acids and alkalies is used as the aqueous solution 49, the effective area of the emitter 1 has a coating which is chemically protective and acoustically non-absorbing (not shown in Figures 14—20). Tetrafluoroethylene polymer can be used as such coating.

In the sound conductor 3 shown in Figure 15, similar to the sound conductor 3 shown in Figure 4, a part of this sound conductor, where the emitter 1 is placed, is made as a hollow body 50 filled with an aqueous solution 51 of a compound selected from Table 3. The contact part of the sound conductor 3 contacting the wall 4 of the reservoir 5 is made of a compound selected from Table 2.

In the sound conductor 3 in Figure 16, also similar to the sound conductor 3 shown in Figure 4, the contact part of the sound conductor 3, contacting the wall 4 of the reservoir 5, consists of a hollow body 52 filled with an aqueous solution 53 selected from Table 3, the part 22 of the sound conductor where the emitter 1 is placed being made of a material selected from Table 2.

In the sound conductor 3 presented in Figure 17, also similar to the sound conductor shown in Figure 4, both parts of the sound conductor 3 have separate bodies 50 and 52 filled with aqueous solutions 51 and 53, respectively, the velocities of the acoustic wave in said solutions having different values C_4 and C_5, respectively. Both parts of the sound conductor 3 are separated by an acoustically conducting partition 54 having a radius of curvature R, said radius being determined from the relationship (3). Such a partition can be made of part of a hollow cylinder having an inner radius R, the cylinder being made of tetrafluoroethylene polymer. The thickness of the partition 54 is adopted to be less than the wave length of the wave 2 of acoustic vibrations by an order of magnitude.

In the contact parts of the sound conductors 3 shown in Figures 16 and 17, the inner surfaces of the hollow bodies 52 are also coated with a layer 21 of a material which absorbs acoustic waves.

The sound conductors 3 presented in Figures 18, 19, and 20 are similar to the respective embodiments of the sound conductors 3 shown in Figures 6, 11, and 12, and comprise a body 48 filled with an aqueous solution 49 of a compound selected from the Table 3 as in the case of the embodiments described above.

All the above-cited embodiments of the device can be successfully used for detecting a fluid-liquid interface.

The method of detecting a gas-liquid or fluid-liquid interface in monolayer reservoirs is accomplished with the above-cited embodiments of the device in the following way.

A wave 2 of acoustic vibrations is launched with the help of an emitter 1 (Figures 1, 2, 3) and introduced through a sound conductor 3 contacting wall 4 of a monolayer reservoir 5 into the wall of the reservoir 5 which is filled with two media 6 (Figure 1) and 7 having an interface 8. The wave 2 is introduced within a section 9 of the reservoir wall 4, said section being located at a prescribed level the presence of the interface 8 at this level being detected by the proposed device.

Prior to introducing the wave 2 of acoustic vibrations into the wall 4, the wave front of the wave 2 of acoustic vibrations is oriented in the sound conductor 3 at an acute or obtuse angle θ (Figure 3) with respect to the wall 4 of the monolayer reservoir 5 and mechanical vibrations 10 are excited by said wave within the section 9 of the wall 4, said mechanical vibrations propagating along the wall 4 in the direction determined by the direction of propagation of the wave 2 and by the angle θ of its entry. In the embodiments of the device shown in Figures 3—20 the angle θ between the front of propagation of the wave 2 and the direction of propagation of the mechanical vibrations 10 being produced is always acute. The angle θ can be obtuse under quite definite conditions, namely, when the mechanical vibrations 10 being excited propagate in the direction opposite to that shown in Figures 3—20. When orienting the wave 2 of acoustic vibrations the velocity C_7 of its trace along the wall 4 of the reservoir 5 is set to be approximately equal to the velocity C of propagation of mechanical vibrations 10 along said wall 4 (i.e. the mechanical vibrations propagate approximately parallel to the surface of the wall)

$$C_7 = \frac{C_3}{\text{Sin } \theta} \cong C \qquad (12)$$

where C_3 is the velocity of propagation of the wave 2 of acoustic vibrations in the sound conductor 3.

The required value of the velocity C_7 of the trace of the wave 2, 13 is set by appropriately selecting the value of the angle of entry θ and the material of the sound conductor 3. The angle of entry θ of the wave 2 of acoustic vibrations into the wall 4 corresponds to the angle of inclination of the effective area 18, of the sound conductor 3, to its contact area 19.

The emitter 1 is excited by electric oscillations either continuous or pulse-amplitude modulated, said electric oscillations being produced by the generator 14.

Mechanical vibrations 10, while propagating along the wall 4, undergo amplitude attenuation, this amplitude attenuation being dependent on the acoustic impedance of a medium 16 (Figures 3—13, 20) contacting the inner surface of the vibrating section 9 of the wall 4. If this medium is gaseous, the amplitude attenuation is minimum; in the event of a liquid medium the amplitude attenuation is maximum. If there are two liquids in the reservoir 5, the attenuation of the mechanical vibrations is greater for the liquid having a higher acoustic impedance.

When mechanical vibrations 10 reach the zone of location of the sound conductor 11 they become partially transformed into the acoustic wave 13 propagating in the sound conductor 11 at an angle to the contact area 19 equal to

$$\frac{\pi}{2} - \theta;$$

this means that they propagate in the direction of the normal to the effective area 18 where the receiver 12 is placed. Said receiver converts the wave 13 into electric signals with an amplitude proportional to that of the mechanical vibrations 10 in the zone of location the sound conductor 11. Electric signals from the receiver 12 come to the input of an amplifier 15 (Figure 5). The amplified electric signals contain information concerning the degree of attenuation of the mechanical vibrations 10 within the section 9 of the wall 4 and, consequently, concerning the location of the interface 8 (Figure 1). These electric signals arrive at the input of the recorder 17 (Figure 3). The location of the interface 8 (Figure 1) is ascertained from the amplitude of the amplified electric signals, which is proportional to the amplitude of the acoustic wave 13 (Figure 3) transformed from the mechanical vibrations 10 propagating along the wall 4.

In particular, if the amplitude of the electric signals being recorded is maximum, the gas-liquid interface 8 (Figure 1) is below the section 9; if the amplitude is minimum, the interface is above said section. When the detected interface 8 is fluid-liquid, the above-considered cases are relevant to liquids one of which has a lower acoustic impedance than the other.

A sudden change in the amplitude of the electric signals being recorded indicates that the interface 8 is passing the level of the vibrating section 9 of the wall 4. This change in the amplitude can be recorded automatically by a recording mechanism or a relay block of the recorder 17 (Figure 3), depending on its particular design.

The above-described method of detecting a gas-liquid or fluid-liquid interface is technologically simple and makes possible effective detection when the cross-section of the wall 4 of the reservoir 5 is constant. A variation of said thickness changes the velocity C of propagation of mechanical vibrations 10 along the wall 4 and, consequently, disturbs the equality between said velocity of propagation of mechanical vibrations and the velocity C_7 of the trace of the introduced wave 2 of acoustic vibrations. This, in turn, causes a decrease in the amplitude of the mechanical vibrations 10 being excited in the wall 4 and, consequently, in the amplitude of the informative electric signal, thus leading to errors in detection of the interface.

To reduce such errors, one should use the method of detecting the gas-liquid or fluid-liquid interface with the help of the device presented in Figure 3 in combination with the embodiments of the sound conductors shown in Figures 4—9.

In an embodiment of the method utilizing such a combination the section 9 of the wall 4 of the monolayer reservoir 5 is excited by a divergent or a convergent wave 2 of acoustic vibrations, the maximum and minimum angles θ_1 and θ_2 of entry of said wave 2 being selected from the relationship (2). For each thickness of the wall 4 (Figure 4) within the range of from d_1 to d_2 and for the respective velocities C of propagation of mechanical vibrations 10 within the range from C_1 to C_2, there is an angle of entry θ lying in the range of from θ_1 to θ_2 and satisfying condition (1) for the optimum excitation of the mechanical vibrations 10.

A divergent wave in the range of angles from θ_1 to θ_2 is formed from the wave 2, originating from the emitter 1, on a cylindrical contact surface 24 of two parts 22 and 23 of the sound conductor 3, (Figure 4) said cylindrical surface having a radius of curvature R. The central ray 25 of the wave 2 passes through the surface 24 without refraction and enters the wall 4 at an angle θ equal to the angle of inclination of the effective area 18 of the sound conductor 3 to the contact area 19 of said sound conductor. Side rays 26 and 27 of the wave 2 are refracted since they fall on the surface 24 not perpendicularly but at an angle ε to the normal, said angle ε being determined by the relationship

$$\operatorname{Sin} \varepsilon = \frac{A}{2R} \qquad (13)$$

where A is the length of the effective area 18 of the sound conductor 3, (or of the emitter 1) and, consequently, of the receiver 12 (Figure 3), in a plane containing the direction of propagation of mechanical vibrations 10 and the normal to the area 18.

After refraction on the cylindrical surface 24 (Figure 4) the rays 26 and 27 propagate in the second part 23 of the sound conductor 3 at an angle ε_1 with respect to the normal to this area 24:

$$\varepsilon_1 = \operatorname{arc Sin}\left(\frac{C_5}{C_4} \operatorname{Sin} \varepsilon\right) = \operatorname{arc Sin} \frac{AC_5}{2C_4R}; \qquad (14)$$

where C_4 and C_5 are the velocities of propagation of the wave 2 of acoustic vibrations in the parts 22 and 23 of the sound conductor 3, and enter the wall 4 at angles θ_1 and θ_2 determined by the relationships:

$$\theta_1 = \theta - \operatorname{arc Sin}\frac{A}{2R} + \operatorname{arc Sin}\frac{AC_4}{2C_5R} \qquad (15)$$

$$\theta_2 = \theta - \operatorname{arc Sin}\frac{AC_5}{2C_4R} + \operatorname{arc Sin}\frac{A}{2R} \qquad (16)$$

In order that the maximum and minimum angles θ_1 and θ_2 of the wave after the refraction correspond to the required divergence or convergence of the wave, the radius of curvature R of the cylindrical surface 24 of contact between the parts 22 and 23 in both sound conductors 3 and 11 (Figure 3), is selected from the relationship (3) satisfying the condition (2) and the expressions (15) and (16). Figure 4 illustrates an example of divergent wave 2 when $C_4 > C_5$. If $C_4 > C_5$ in the example illustrated in Figure 4, then the wave 2 will be convergent. The convergence or

divergence of the wave may also be dependent upon the curvative of surface 24. In the accomplishment of this, latterly described embodiment which eliminates errors associated with diminishing of the informative electric signal, in the manufacture of the sound conductors 3 and 11 with a cylindrical contact surface 24 is rather sophisticated. A simpler design of the sound conductors 3, 11 is resorted to in another embodiment of the device, which is shown in Figures 6 and 7.

In this embodiment (Figures 6 and 7) the sound conductors (3, 11) have a cylindrical effective area 18, while the emitter 1 and receiver 12 (Figure 3) of the acoustic wave 13 have effective areas similar to the effective areas 18 of the sound conductors (3, 11), this ensuring divergence or convergence of the wave (2, 13) of acoustic vibrations. Divergence of the wave 2 takes place when the effective area 18 of the sound conductor 3 is concave and convergence (shown in Figure 6) takes place when this area is convex. The central ray 25 of the wave 2 enters the wall 4 at an angle equal to the angle between the tangent to the centre of the effective area 18 and the contact area 19 of the sound conductor 3. Side rays 26 and 27 of the wave 2 enter the wall 4 at angles θ_1 and θ_2 which are greater or smaller, respectively, than the angle θ by the value ε determined by the relationship (13):

$$\theta_1=\theta+\text{arc Sin}\frac{A}{2R,} \qquad (17)$$

$$\theta_2=\theta-\text{arc Sin}\frac{A}{2R} \qquad (18)$$

For the angles θ_1 and θ_2 determined by these relationships (17) and (18) to satisfy the condition (2) of the required convergence or divergence of the wave 2, the length A of the effective area 18 of the sound conductor 3 (or of the emitter 1 and, correspondingly, of the receiver 12) should be selected in accordance with the relationship with the radius R of the curvature of the effective area 18 given in (4).

The device shown in Figures 6 and 7 makes it possible to diminish the above-stated errors when detecting the interface 8 (Figure 1) by making the effective areas 18 of the sound conductors 3, 11 cylindrical, without any limitations as to the wave length of the wave 2 of the acoustic vibrations.

An embodoment of the device utilizing the sound conductor 3 shown in Figures 8 and 9 is similar than the above-considered embodiments, although it necessitates certain limitations as far as the wave-length λ of the wave 2 of acoustic vibrations is concerned.

In this embodiment of the device the minimum distance H_{min} between the effective area 18 and the contact area 19 of the sound conductor 3 is selected according to the relationship (6) so that the path of propagation of the side ray 27 should exceed the length B of the Fresnel zone in the acoustic field of the emitter 1, within which the wave 2 has a plane front 28 of non-divergent vibrations. Leaving this zone, the plane front 28 of the wave 2 is transformed into a partially spherical front with a divergent bundle of acoustic rays, the side rays 26, 27 entering the wall 4 at angles θ_1 and θ_2, respectively, θ_1 being greater and θ_2 smaller than the angle θ of the entry of the central ray 25.

At a sufficiently great distance from the boundary of the Fresnel Zone, the angle of divergence of the wave 2 is determined by the directivity pattern of the emitter 1 and almost all the energy of acoustic emission is confined within the angle of divergence which is equal to

$$\theta_1-\theta_2=1.4\ \text{arc Sin}\frac{K_1\lambda}{A} \qquad (19)$$

where k_1 is a coefficient determined by the shape of the effective area 18 of the sound conductor 3, equal, for example, to 1.22 for a spherical and to 1 for a rectangular shape. Therewith the angles θ_1 and θ_2 are determined by the following equations:

$$\theta_1=\theta+0.7\ \text{arc Sin}\frac{K_1\lambda}{A} \qquad (20)$$

$$\theta_2=\theta-0.7 \text{ arc Sin}\frac{K_1\lambda}{A} \quad (21)$$

The solution of the set of equations (2), (20), and (21) gives the relationship (5) between the length A of the effective area 18 and the wavelength λ, said relationship ensuring the required divergence of the wave 2 and, consequently, optimum excitation of the section 9 (Figure 3) of the wall 4 of the reservoir 5 within the range from C_1 to C_2 of the velocities of propagation of mechanical vibrations 10.

The device shown in Figure 3, and further embodiments using the different designs of the sound conductors 3 (shown in Figures 4—9), has a simple electronic circuit allowing for the detection to be performed when the amplitude instability (with respect to time) of the electric oscillations of the generator 14 is small, said oscillations being used for excitation of the emitter 1. Changes in the amplitude of the electric oscillations of the generator 14 require either periodic readjustment of the recorder 17 or varying the gain factor of the amplifier 15, which affects the efficiency and stability of the detection system.

The use of the embodiment of the device shown in Figure 10 can enhance both the efficiency and stability of the detection of gas-liquid or fluid-liquid interface.

In this embodiment (Figure 10) of the device a reference electric signal in an analogue or digital form is shaped by the shaper 29 from the electric oscillations of the generator 14; and informative electric signal is shaped in the same form by the shaper 31 from electric signals of the amplifier 15; said reference and informative electric signals are compared in the comparison block 30. The output signal of the comparison block 30, which is proportional to the difference or to the ratio between the signals compared, goes to the recorder 17. Since the amplitude instability of the electric signals of the generator 14 equally affects the value of the informative and of the reference signals, the results of the interface detection do not depend on said instability.

The described device in combination with the sound conductors (Figures 4—9) is very efficient in the event of various amplitude instabilities of the electric oscillations of the generator 14 and when the velocity C of mechanical vibrations 10 of the excited section 9 of the wall 4 of the reservoir 5 changes within the range of C_1 to C_2. However, the amplitude of the mechanical vibrations 10 (Figure 10) changes when the conditions of entry of the wave 2 into the wall 4, through the contact surface 19 of the sound conductor 3, vary during stationary operation of the device or during rapid detection or control of the interface 8 (Figure 1). Such variations in the conditions of entry may be caused, for example, by different thickness of the cement between the contact area 19 of the sound conductors 3 and 11 and the wall 4 of the reservoir 5 (if the sound conductors are cemented to the wall), by roughness on the surface of the wall 4 during dynamic detection of the interface, as well as by cracking, stripping off, or partial destruction of the contact layer, which may bond together the contact area 19 of the sound conductors 3, 11 and the wall 4 of the reservoir 5, during the detection of a stationary interface. Said variations require periodic readjustment of the shaper 31 of the informative electric signal, and the timing of readjustment can bring about significant errors in the interface detection.

It is possible to diminish such errors by employing a method of detecting a gas-liquid or fluid-liquid interface accomplished with the use of the devices shown in Figures 11 and 12.

In this embodiment of the method of detecting the interface, within the section 9 of the wall 4 mechanical vibrations 38 are excited by a wave 34 of acoustic vibrations, the attenuation of these mechanical vibrations being different from the attenuation of the mechanical vibrations 10 excited by the primary wave 2. In this case a change in the conditions of entry of the waves 2 and 34 into the wall 4 as well as a change in the amplitude of the electric oscillations of the generator 14 cause similar variations in the amplitudes of the primary and secondary mechanical vibrations 10, 38. In a similar way, a change in the parameters of the contact area 19 in the sound conductor 11 causes a similar change of the acoustic wave 13, transformed from the mechanical vibrations 10 primarily excited within the wall 4, and of the acoustic wave 36 transformed from the mechanical vibrations 38 excited in the wall 4. Owing to the above, it is possible to detect the interface 8 (Figure 1) between the media 6 and 7 from the relationship between the amplitudes of the mechanical vibrations 10 (Figures 11 and 12) and 38, excited by the primary and

secondary waves 2 and 34 of acoustic vibrations, irrespective of changes in the conditions determined by the entry of the waves 2 and 34 through the contact area 19 in the sound conductor 3 or of changes caused within the contact area 19 of the sound conductor 11.

In the device shown in Figure 11, the wave 34 is introduced into the wall 4 for a secondary excitation of mechanical vibrations 38 with the help of additional emitter 33. Said additional emitter is oriented in such a way that its effective area, coinciding with additional effective area 32 of the sound conductor 3, makes an angle γ with the contact area 19, said angle γ being selected from the relationship (7). The wave 34 is introduced into the wall 4 at said angle γ. Acoustic wave 13, transformed from the primary excited mechanical vibrations 10, propagate at an angle θ with respect to the normal to the contact area 19 and enters the main receiver 12 along the normal to its effective area. Acoustic wave 36 transformed from the mechanical vibrations 38 secondarily excited in the wall 4, propagates in the sound conductor 11 at an angle γ with respect to the normal to its contact area 19 and enters the additional receiver 35 along the normal to its effective area.

From the electric signals of the main receiver 12 which have passed through the main amplifier 15, the shaper 31 shapes (in a digital or an analogue form) an informative electric signal with an amplitude proportional to that of the primary excited mechanical vibrations 10 which have entered the zone of location of the sound conductor 11. Another shaper 29 shapes a reference electric signal from the electric signals which have come from the additional receiver 35 and passed through the additional amplifier 37, the amplitude of said reference electric signal being proportional to the amplitude of mechanical vibrations 38 excited in the zone of location of the sound conductor 11. Both reference and informative electric signals of the shapers 29 and 31 are equally affected by instabilities arising within the contact area 19 of the sound conductor 3, upon introduction of the waves 2 and 34 of acoustic vibrations, and within the contact area 19 of the sound conductor 11, upon transformation of the primary and secondarily excited mechanical vibrations 10, 38, into the acoustic waves 13 and 36, respectively. Owing to this, the output signal of the comparison block 30, produced from the informative and reference signals entering said block, is proportional to the ratio between said signals and does not depend on the above-stated instabilities.

Since mechanical vibrations 10, 38 produced by primary and secondary excitations have different attenuation in the wall 4 of the reservoir 5 caused by partial leakage of their energy into the medium 16 contacting the inner surfaces of the vibration section 9 of said wall 4, the output signal of the comparison block 30 provides unambiguous information concerning the location of the interface 8 (Figure 1) between the media 6 and 7 in the reservoir 5, this information being, recorded by the recorder 17.

Combination of the zones of entry of the main and additional waves 2, 34 of acoustic vibrations within the contact area 19 of the sound conductor 3, as well as combination of the zones of transformations of mechanical vibrations 10, 38, produced by the primary and secondary excitation, into the main acoustic wave 13 and into the additional acoustic wave 36, within the contact area 19 of the sound conductor 11, are attained by selecting the distance E between the projections of the centres of the main and additional effective areas 18, 32 onto the contact area 19 and the perpendicular distances H_1 and H_2 from the contact area 19 to these centres in accordance with the relationship (8).

Although the present device eliminates effectively the influence of the above-stated instabilities and the electronic circuit of the device is comparatively simple, changes are possible in the transformation properties of the emitters, and this may lead to corresponding errors.

Such errors can be diminished by realizing the described method accomplished with the use of the embodiment shown in Figure 12, which employs one emitter 1, one receiver 12, and a more sophisticated electronic circuit. In this case an additional wave 34, introduced at an angle γ into the wall 4 and used for secondary excitation of mechanical vibrations 38 in said wall 4, is created by reflecting one part of a wave 40 of the emitter 1 of acoustic vibrations from a reflecting area 39 of the sound conductor 3, said reflecting area making an angle β with the effective area 18, the angle β being determined from the relationships (7) and (9) as

$$\frac{\pi}{2} + \gamma - \theta$$

another part of the wave 2 from the emitter is introduced into the wall 4 at an angle θ and is used for primary excitation of mechanical vibrations 10 in the wall 4 within the section 9. In the sound conductor 11 the primary excited mechanical vibrations 10 are transformed into the main acoustic wave 13 propagating at an angle θ with respect to the normal to the contact area 19 of said sound conductor. The secondarily excited mechanical vibrations 38 are transformed in the sound conductor 11 into the acoustic wave 36 propagating at an angle γ with respect to the normal to the contact area 19 in the direction towards the reflector area 39. The wave 36 is reflected from said reflector area and, as an additional acoustic wave 41, enters the receiver 12 along the normal to its effective area.

The secondary excited mechanical vibrations 38 have the velocity C_6 of propagation along the wall 4, said velocity being different from the velocity C of the primarily excited mechanical vibrations 10 (in the embodiment of the device shown in Figure 12 $C_6>C$). Therefore, with the wave front of mechanical vibrations 10 along the wall 4 considerably exceeding the front of the mechanical vibrations 38, the main and the additional acoustic waves 13 and 41 enter the receiver 12 with a time shift $\Delta\tau$ with respect to each other, said shift essentially exceeding the duration τ of the pulse-amplitude modulated electric oscillations, produced by the generator 14, which are sent to the emitter 1 as previously described. Owing to this, the main and additional electric pulse signals of the receiver 12, having their amplitudes proportional to the amplitudes of the primarily and secondary excited mechanical vibrations 10 and 38, are separated in time.

Pulse signals from the receiver 12 pass through the common amplifier 15 to the inputs of the selection blocks 42 and 43, the control inputs of which are fed with selecting pulses derived from the output of the shaper 44. The selecting pulse supplied to the selection block 42 corresponds to the timing of the main pulse signal, and the selecting pulse supplied to the block 43 corresponds to the timing of the reference pulse signal.

The main and additional electric signals separated in the selection blocks 42 and 43, respectively, are supplied to the shaper 31, adapted to shape an informative electric signal, and to the shaper 29, adapted to shape a reference electric signal, they are then fed to the inputs of the comparison block 30. From the output of this block, the signal carrying unambiguous information concerning the interface being detected is sent to the recorder 17.

The above-disclosed method of detecting an interface in monolayer reservoirs provides highly accurate and stable control in the course of long-term operations. At the same time this method makes it possible to diminish the errors caused by instabilities occurring when the wave of acoustic vibrations is introduced into the wall of the reservoir and when the mechanical vibrations excited within the reservoir wall are transformed into an acoustic wave in the zone of the contact area of the sound conductor on which the receiver is mounted. However, in the above-described method errors may take place as a result of changes in the wave propagating properties of the reservoir walls.

These errors can be diminished when the method of detecting a gas liquid or fluid-liquid interface in monolayer reservoirs is accomplished with the use of a device an embodiment of which is shown in Figure 13.

With this method, the section 9 of the wall 4 of the reservoir 5 is periodically excited with a pulse wave 2 of acoustic vibrations. The frequency spectrum of said pulse is selected from a range including but exceeding the range of preferred frequencies of the wall 4. Wide-spectrum pulses produced by the shaper 45 (Figure 13) and passed through the power amplifier 46 act upon the emitter 1. These pulses have the form of rectangular video-pulses with a duration τ_0, said duration being determined by the relationship (10). As a result, the emitter 1 emits into the sound conductor 3 a spectrum of ultrasonic vibrations, covering all the values of the preferred frequencies of the wall 4 with the interfaces 8 (Figure 1) being found in different positions.

A signal from the receiver 12, transformed by said receiver from the acoustic wave 13 (Figure 13) which in turn is transformed from the mechanical vibrations 10 entering the zone of the contact area 19 of the sound conductor 11, consists of a number of electric oscillations, which may be considered as a pulse signal (the shape of these electric oscillations being similar to the received pulse acoustic wave 13), depending on the position of the interface 8 (Figure 1). The frequency f of the electric oscillations also depends on the type of the medium 16 (Figure 13) contacting the vibrating section 9 of the wall 4 of the reservoir 5.

Said frequency f is recorded in block 47 which is adapted to measure the

frequency of electric signals, the signals being fed to block 47 from the receiver 12 through the amplifier 15. The frequency thus measured is used for ascertaining the type of liquid (characterized, for example, by the value of its acoustic impedance) when the interface 8 (Figure 1) is found above or below the vibrating section 9 of the wall 4 (Figure 13) of the reservoir 5.

An informative signal is shaped in shaper 31 from pulse signals of the receiver 12, these pulse signals being fed to said shaper 31 through the amplifier 15. The amplitude of said informative signal thus formed is proportional to the amplitude of the received pulse signals. A reference electric signal is shaped from the video-pulses, taken from the output of the power amplifier 47, in shaper 29. Said reference signal and the informative electric signal pulse are supplied to the comparison block 30. The output signal of block 30 furnishes information concerning the interface 8 (Figure 1) being detected and is recorded by recorder 17 (Figure 13).

The abovedescribed embodiment of the method effectively reduces the influence of changes in the resonant frequency of mechanical vibrations, caused by different positions of the interface and permits the additional detection of the type of liquid when the thickness of the wall section being excited is constant. However, errors may arise when said thickness varies considerably, thus causing a change in the resonant frequency of mechanical vibrations within a wider range than in the event of changes in the interface position in the reservoir.

These errors are reduced when the method of detecting a gas-liquid or fluid-liquid interface is accomplished by the use of a device such as that shown in Figure 13.

In this method, section 9 of the wall 4 of the reservoir 5 is periodically excited by a pulse wave 2 of acoustic vibrations, the relative width of the spectrum of said wave being selected in accordance with relationship (11) that is equal to or exceeding the relative variation in the thickness of the vibrating section 9 of the wall 4 of the reservoir 5. This is attained by manufacturing the sound conductors 3 and 11 of for example, fused quartz, porcelain, silicate glass, lead, tin, or lead-tin alloys, having an acoustic impedance within the range of 0.3 to 1.7 of acoustic impedance of the emitter 1 and receiver 12 of the acoustic wave. The materials from which the sound conductors may be made are specified in Table 2.

Such design of the sound conductors 3 and 11 provide acoustic damping of the emitter 1 and of the receiver 12 with a corresponding broadening of the boundaries of the emission and reception spectra of the waves 2 and 13 of acoustic vibrations. A decrease in the acoustic impedance of the sound conductors 3 and 11, which depends on the material of sound conductors, with respect to the acoustic impedance of the emitter 1 and of the receiver 12 diminishes the respective spectra width. The type of material of the sound conductors 3 and 11 and, correspondingly, its impedance (see Table 2) are selected in accordance with the spectrum width by the relationship (11).

The method described above ensures detection of the interface and allows information as to the liquid type to be obtained when the interface is located above or below the reservoir wall section being excited providing that the interface excerts a perceptible loading on the wall section being excited and in the case of a gas-liquid system the interface is above the section). However, detection errors may arise because of temperature changes. The value of said errors is determined mainly by the temperature dependence of the velocity of propagation of the wave of acoustic vibrations in the sound conductors.

Temperature errors can be substantially diminished by using the devices for controlling gas-liquid or fluid-liquid interface shown in Figures 3—13 with the sound conductors designed as shown in Figures 14—20.

The reduction of temperature errors is attained in that the sound conductors 3 and 11 are made on the bases of aqueous solutions of alcohols, alkalies, acids, or salts of inorganic acids which have an almost parabolic dependence of the velocity C_3 of propagation of the acoustic wave 2, 13 on the temperature t.

$$C_3=C_{3max}\,[1-(t-to)^2], \qquad (22)$$

where C_{3max} is the maximum velocity of propagation of the wave 2, 13 in an aqueous solution when $t=t_o$.

The concentration q of the solution is so selected that the maximum value C_{3max} of the velocity of propagation is in the region of the average temperature t_o of the wall 4 of the reservoir 5. Owing to this, the velocity of the acoustic wave in the

sound conductor 3 over the operating temperature range varies very little. For example, when the temperature changes are within ±20°C of the average value t_0, the velocity usually varies by no more than 0.6%. This essentially increases the accuracy of the interface detection.

The above disclosed method of detecting a gas-liquid or fluid-liquid interface in a monolayer reservoir accomplished with the use of devices embodiments of which are shown in Figures 3—20 provides a highly effective non-contact automatic detection of interfaces in reservoirs during various technological processes in metallurgical, ore-dressing, chemical, petrochemical, food stuffs, and other industries.

The above description discloses various problems which are encountered when using such a detection system and the solutions to these problems in order to overcome the most pertinent problems combinations of the above-disclosed solutions may be chosen.

WHAT WE CLAIM IS:—

1. A method detecting a fluid-liquid interface in a container having a wall homogeneous across its thickness comprising the steps of; producing acoustic vibrations, introducing the acoustic vibrations into a sound conducting medium which contacts a wall of the container in such a fashion that mechanical vibrations are excited within the wall, the mechanical vibrations propagating in a direction transverse to the thickness of the wall, sensing the mechanical vibrations by positioning a second sound conducting medium on the wall of the container in the path of the mechanical vibrations such that acoustic vibrations are excited within the second sound conductor, detecting the relative position of the interface by analyzing the amplitude attenuation due to energy dissipation by the mechanical vibrations while propagating within the wall of the container.

2. A method as claimed in Claim 1, wherein the thickness of the section of the wall lying between the sound conductors varies, comprising the step of exciting the section of the wall a divergent or convergent wave of acoustic vibrations, the maximum and minimum angles θ_1 and θ_2 of entry of this wave being selected from the relationship:

$$\frac{\sin\theta_1}{\sin\theta_2} \geqslant \frac{C_1}{C_2},$$

where θ_1 and θ_2 are angles of entry of the wave of acoustic vibrations, determined by the direction of propagation of the wave and the normal to the container wall at the point of entry;

C_1 and C_2 are respective maximum and minimum velocities of propagation of mechanical vibrations within the section of the container.

3. A method as claimed in Claims 1 or 2, wherein the thickness of the said section of the wall varies, comprising the step of exciting further mechanical vibrations within the section of the wall with the aid of a second wave of acoustic vibrations, the attenuation of these latter mechanical vibrations being different from that of the mechanical vibrations excited by the first wave of acoustic vibrations, the location of the interface being ascertained from the relationship between the amplitudes of the mechanical vibrations excited by the said first and the said second waves of acoustic vibrations.

4. A method as claimed in any of Claims 1, 2 or 3, comprising the step of periodically exciting the said section of the wall by a pulsed wave of acoustic vibrations having a frequency spectrum; and monitoring the frequency of the propagating wave so as to ascertain the type of liquid.

5. A method as claimed in Claim 2 or 3, comprising the step of periodically exciting the said section of the wall by a pulse wave of acoustic vibrations, the relative width of the spectrum thereof being selected equal to or exceeding the relative variation in the thickness of the section of the container wall being excited.

6. A device for detecting a fluid-liquid interface in a container having a wall homogeneous across its thickness, comprising an emitter and a receiver of acoustic vibrations each mounted in contact with a respective sound conducting medium, one sound conducting medium contacting a section of the wall of the container in such a fashion that mechanical vibrations are excited within the section of the wall by acoustic vibrations emitted by the emitter to propagate in a direction transverse to the thickness of the wall, the other sound conducting medium contacting the section of the wall in the path of the mechanical vibrations and in such a fashion

that acoustic vibrations are excited within the sound conducting medium and impinge upon the receiver, means being provided for determining the relative position of the interface by an analysis of the amplitude attenuation due to energy dissipation by the mechanical vibrations while propagating within the wall of the container.

7. A device as claimed in claim 6, wherein the emitter is connected to an oscillator and the receiver has its output connected to a circuit comprising a series connected amplifier and recording unit for recording the relative amplitude output of the receiver.

8. A device as claimed in claim 6 or 7, wherein the surfaces of the sound conductors contacting the wall of the container and the surfaces contacting the respective emitter or receiver are inclined at angles θ to each other, these angles being determined from the relationship:

$$\theta = \text{arc Sin } C_3/C$$

where C_3 is the velocity of propagation of the wave of acoustic vibrations within the sound conductors, and

C is the velocity of propagation of mechanical vibrations along the container wall, the sound conductors being made of a material wherein C_3 is less than C.

9. A device as claimed in any of Claims 6, 7 or 8 wherein the thickness of the said section of the wall varies, comprising sound conductors consisting of two parts, the material of each of the two parts differing as to the velocity of propagation of acoustic vibrations within them, each of the two parts having part cylinder areas of contact, with the axis of symmetry of these areas lying in the same plane as the respective axis of the emitter or of the receiver, with the axis of symmetry being perpendicularly to the respective axis of the emitter or receiver, the radius of the contact areas being determined from the relationship.

$$R \leqslant \frac{C_1 + C_2}{C_4 + C_5} \left| \frac{C_4 - C_5}{C_1 - C_2} \right| A \, Ctg \, \theta \, ;$$

where C_1 and C_2 are respective maximum and minimum velocities of propagation of mechanical vibrations within the section of the container wall, C_4 and C_5 are the velocities of propagation of the wave of acoustic vibrations in the different parts of the sound conductors,

A is the length of the contact area of the sound conductor with its respective emitter or receiver in a plane containing the direction of propagation of the mechanical vibrations and the normal to the said contact area, and θ is the angle between the wave of acoustic vibrations and the normal to the wall at the point of entry of the wave thus ensuring divergence or convergence of the wave of acoustic vibrations.

10. A device as claimed in Claim 8, wherein the thickness of the said section of the container wall varies comprising sound conductors having part cylinder shaped areas of contact with their respective emitter or receiver the radius of curvature of the contact area being determined from the relationship:

$$R \leqslant \frac{C_1 + C_2}{2(C_1 - C_2)} . A \cot\theta,$$

where C_1 and C_2 are the respective maximum and minimum velocities of propagation of mechanical vibrations within the section of the container wall,

A is the length of the contact area of the sound conductor with its respective emitter or receiver in a plane containing the direction of propagation of the mechanical vibrations and the normal to the said contact area, and

θ is the angle between the wave of acoustic vibrations and the normal to the wall at the point of entry of the wave.

11. A device as claimed in Claim 8, wherein the thickness of the said section of the wall varies, comprising contact areas, of the sound conductors with their respective emitter or receiver of length A in the plane containing the normal to the said contact area and the direction of propagation of the mechanical vibrations, the said length A being determined from the relationship:

$$A \leqslant K\frac{C_1+C_2}{C_1-C_2}.\lambda \text{ Cot}.\theta,$$

where k is a coefficient determined by the shape of the said contact areas of the sound conductors,

λ is the wavelength of the wave of acoustic vibrations in the sound conductors, the minimum distance H_{min} between the centres of the said contact areas and the wall of the container being determined from the relationship:

$$H_{min} > \frac{A^2}{\mu\lambda}.\text{Cos}\theta,$$

thus ensuring divergence or convergence of the wave of acoustic vibrations.

12. A device as claimed in any of Claims 6, 7 or 8, wherein the said section of the container wall is re-excited by the wave of acoustic vibrations, the sound conductors each having a second respective emitter or receiver placed in contact with them at an angle γ to the surface of the container wall, said angle γ being determined from the relationship:

$$\gamma = \text{arc Sin}\frac{C_3}{C_6}$$

where C_6 is the velocity of propagation of the mechanical vibrations which are re-excited within the container wall.

13. A device as claimed in claim 12, wherein the said second emitter is connected to an oscillator in parallel with the first emitter, and the second receiver is connected to an input of a second amplifier, the output of the second amplifier being connected to an input of a shaper of a reference signal, the output of the shaper being connected to an input of a unit adapted to compare a data signal with the reference signal, another input of the said unit being connected to an output of a shaper adapted to shape the data signal, the input of the data signal shaper being connected to the output of the first amplifier, the output of the comparator unit being connected to the input of a recorder of the amplitude of the output signal.

14. A device as claimed in Claim 12 or 13, wherein the distance E between the projections of the centres of the first and the second contact areas, between the sound conductors on and the respective emitters or receivers, the wall of the container is determined from the relationship:

$$E = H_1 \tan\theta - H_2 \tan\gamma$$

where H_1 and H_2 are the respective perpendicular distances between the wall of the container and the centres of the said first and second contact areas.

15. A device as claimed in Claim 8, wherein, the said section of the container wall is re-excited by the wave of acoustic vibrations, the sound conductors having a reflector area making an angle β with the area of contact between the second conductors and their respective emitter or receiver, this angle β being determined from the equation:

$$\beta = \frac{\pi}{2} - \left(\theta - \text{arc Sin}\frac{C_3}{C_6}\right);$$

16 A device as claimed in Claim 15, wherein the emitter is connected to an oscillator and the receiver has its output connected to a circuit comprising a series connected amplifier and a recording unit for recording the relative amplitude output of the receiver, the output of the amplifier is connected to two circuits, the input of the first circuit being an input of a first timing unit, a control input thereof being connected to an output of a timing pulse shaper, and its output being connected to the input of a data signal shaper being connected to the input of a comparator unit, which compares the data signal with a reference signal; the input of the second circuit being an input of a second timing unit, a control input thereof being connected to a second output of the timing pulse shaper, the output of the second timing unit being connected to the input of a reference signal shaper, the

output of this shaper being connected to a second input of the comparator unit, the output of the comparator block being connected to the recorder, the input of the timing pulse shaper being connected to the output of the oscillator, which produces pulse-amplitude modulated oscillations.

17. A device as claimed in any of Claims 6 to 11, wherein said section of the container wall is excited by a pulse wave of acoustic vibrations, the emitter is connected to an oscillator, the oscillator incorporating a pulse shaper and an amplifier of the pulses, the amplifier being connected to the output of the said shaper, the outputs of the amplifier constituting the outputs of the oscillator, one of which is connected to the input of a reference signal shaper, the output of the latter shaper being connected to the input of a comparator unit, which compares a data signal with a reference signal, the output of the comparator unit being connected to the input of a recorder, which records the relative amplitude output of the receiver, input of the comparator unit is connected to the output of a data signal shaper, the input thereof being connected to an output of an amplifier the input of which is connected to the receiver, a second output of the amplifier of electric signals coupled also the output of a block being connected to a unit which moniters the frequency of the output of the receiver.

18. A device as claimed in Claim 16, wherein the sound conductors are manufactured of fused quartz, porcelain, silica glass, lead, tin, or lead-tin alloys having an acoustic impedance within the range from 0.3 to 1.7 of the acoustic impedance of the emitter and the receiver of the wave of acoustic vibrations, respectively.

19. A device as claimed in any of Claims 6 to 17, wherein the sound conductors are made on the basis of aqueous solutions of alcohols, alkalies, acids, or salts or inorganic acids, having a substantially parabolic of the velocity of propagation of the wave of acoustic vibrations upon the temperature of the solution, the concentration of the solutions being such that the maximum velocity of propagation of the waves lies within the zone of the mean temperature of the said section of the container wall.

20. A method of detecting a fluid-liquid interface in a container, substantially as herein described.

21. A device for detecting a fluid-liquid interface in a container, substantially as herein described with reference to the accompanying drawings.

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1555549 COMPLETE SPECIFICATION

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Sheet 1

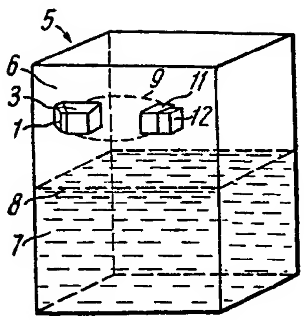


FIG.1

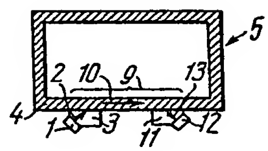


FIG.2

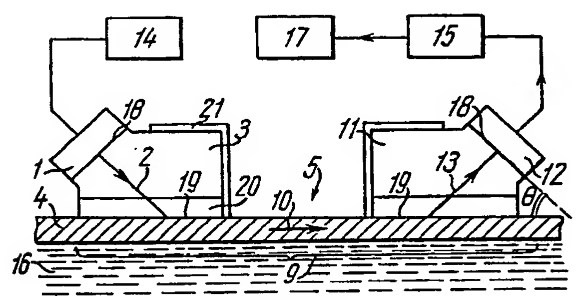


FIG.3

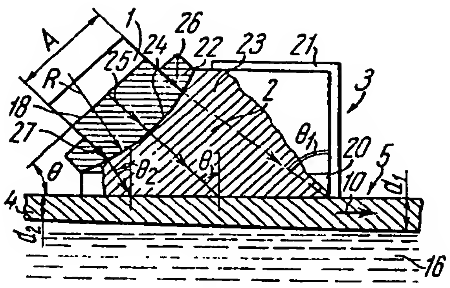
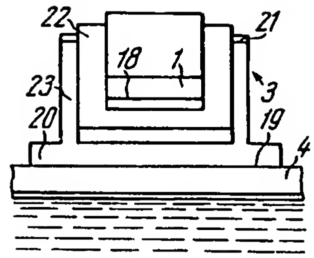


FIG. 4



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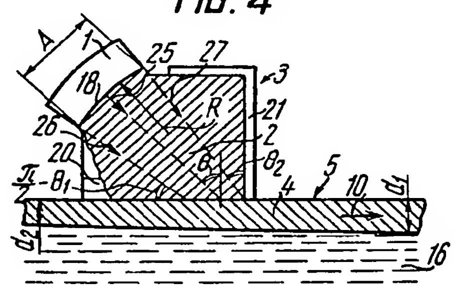

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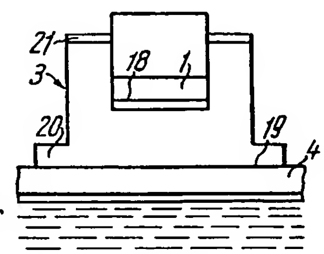
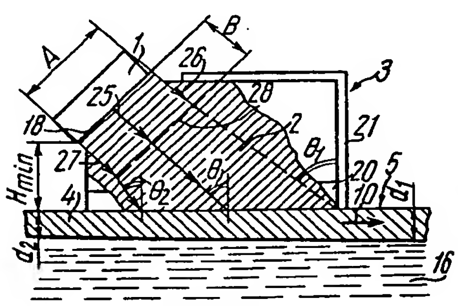


FIG.7



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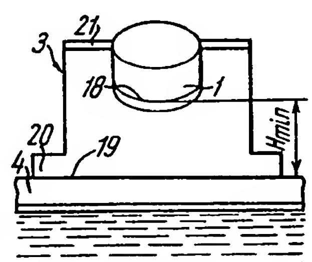

FIG. 9

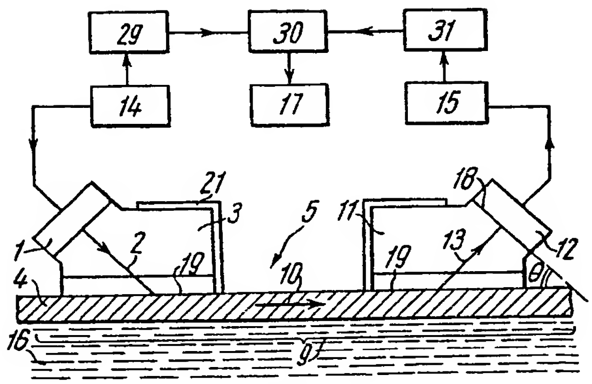
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FIG.10

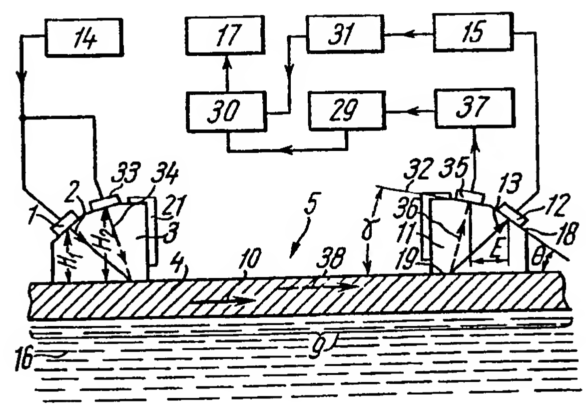
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FIG.11

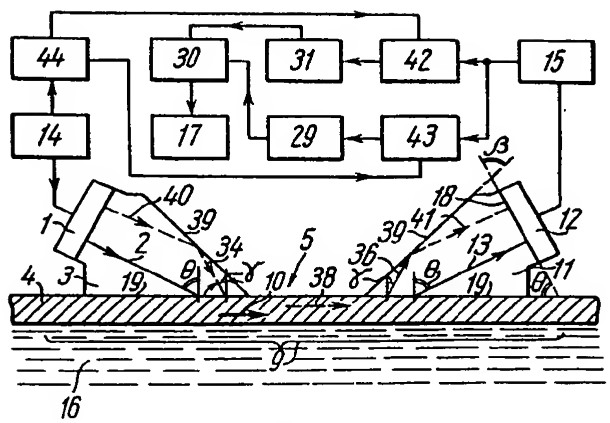
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FIG.12

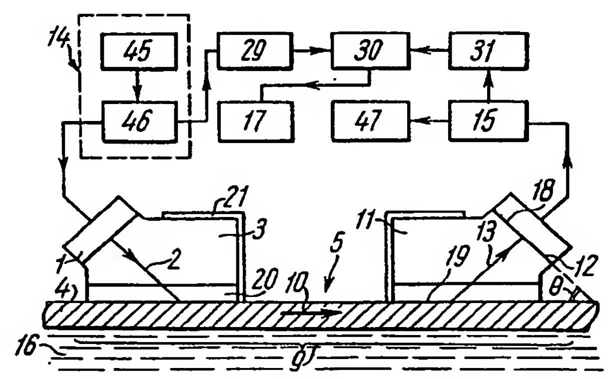
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FIG.13

1555549 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 5

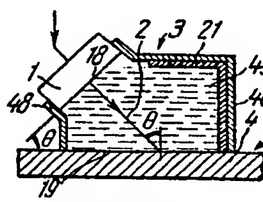

FIG.14

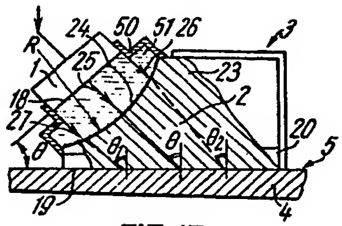

FIG.15

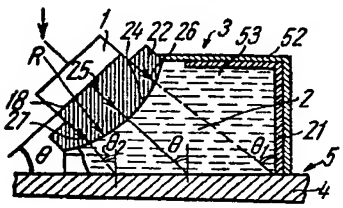

FIG.16

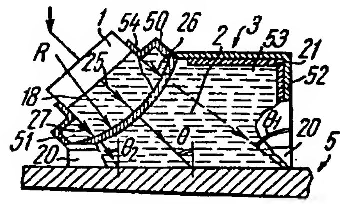

FIG.17

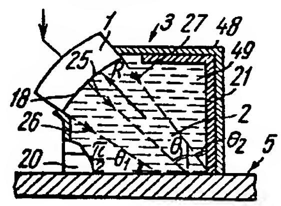

FIG.18

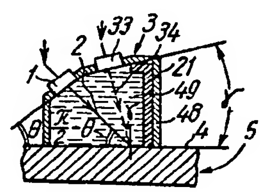

FIG.19

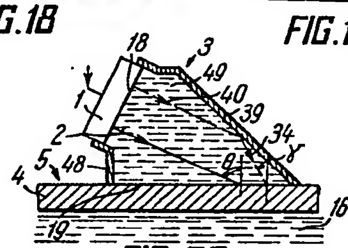

FIG. 20